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Manure and Mineral Fertilizer Effects on Crop Yield and Soil Carbon Sequestration: A Meta-Analysis and Modeling Across China

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Abstract

©2018. American Geophysical Union. All Rights Reserved. Manure application to soil has declined globally due to increased availability of mineral fertilizers. However, mineral fertilizer overuse has caused serious consequences for soil quality and the environment. We analyzed the results of 20 long-term field trials (22–32 years, start year [ranged from 1980 to 1990] to 2012) and combined this with a climate change model and soil organic carbon (SOC) model to quantify the importance of manure and mineral fertilizers for grain yield and SOC sequestration across croplands in China. During the past three decades mineral fertilizers have increased grain yield for 91–184% but had minor impact on SOC sequestration (4–16%). In contrast, manure applied with mineral fertilizer increased grain yield by only 6–19% but strongly raised the SOC content (9–39%) compared with mineral fertilizer. Modeling (to the year 2099) indicated that manure used in combination with mineral fertilizers will increase future C sequestration in soils across China by 2,086 Tg C and by 2,482 Tg C based on current net primary productivity with no climate change and on increased net primary productivity with climate change scenarios, respectively. This corresponds to an additional 43–58% increase in C sequestration compared to mineral fertilizers only. The manure efficiency for C sequestration in soil was about 9.6% of C input and decreased with increasing SOC content. To maintain the current SOC content (i.e., 2010), 11 t·ha−1·year−1 fresh manure or 4.8 t·ha−1·year−1 dry maize straw would be required. We conclude that the regular use of manure with mineral fertilizers is essential for the long-term dual functions of soil for food production and SOC sequestration.

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Keywords

carbon sequestration, climate change, long-term experiments, manure, RothC model

References

[1] Álvaro-Fuentes, J., Easter, M., & Paustian, K. (2012). Climate change effects on organic carbon storage in agricultural soils of northeastern Spain. Agriculture, Ecosystems and Environment, 155, 87–94. https://doi.org/10.1016/j.agee.2012.04.001

[2] Bhogal, A., Chambers, B. J., Whitmore, A. P., & Powlson, D. S. (2007). The effects of reduced tillage practices and organic material additions on the carbon content of arable soils. Scientific report for Defra Project, SP0561, ADAS UK Ltd. (48 pp.). Retrieved from http://www.doc88.com/p-2728730427887.html (accessed 27 December 2017)

[3] Black, C. A. (1965). Methods of soil analysis, part 2 (Vol. 100, p. 376). Madison, WI: ASA. https://doi.org/10.1097/00010694-196511000-00020

[4] Castellano, M. J., Mueller, K. E., Olk, D. C., Sawyer, J. E., & Six, J. (2015). Integrating plant litter quality, soil organic matter stabilization and the carbon saturation concept. Global Change Biology, 21(9), 3200–3209. https://doi.org/10.1111/gcb.12982

[5] Cesarano, G., Filippis, F. D., Storia, A. L., Scala, F., & Bonanomi, G. (2017). Organic amendment type and application frequency affect crop yields, soil fertility and microbiome composition. Applied Soil Ecology, 120, 254–264. https://doi.org/10.1016/j.apsoil.2017.08.017

[6] Coleman, K., & Jenkinson, D. (1999). RothC-mod26.3. A model for the turnover of carbon in soil model description and windows users guide Rothamsted research, Harpenden, Herts, AL5 2JQ UK. https://doi.org/10.1007/978-3-642-61094-3_17

[7] Davidson, E. A., & Janssens, I. A. (2006). Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature, 440(7081), 165–173. https://doi.org/10.1038/nature04514

[8] Dawe, D., Dobermann, A., Ladha, J. K., Yadav, R. L., Bao, L., Gupta, R. K., Lal, P., Panaullah, G., Sariam, O., Singh, Y., Swarup, A., & Zhen, Q.-X. (2003). Do organic amendments improve yield trends and profitability in intensive rice systems? Field Crops Research, 83(2), 191–213. https://doi.org/10.1016/S0378-4290(03)00074-1

[9] Fan, T., Xu, M., Song, S., Zhou, G., & Ding, L. (2008). Trends in grain yields and soil organic C in a long-term fertilization experiment in the China loess plateau. Journal of Plant Nutrition and Soil Science, 171(3), 448–457. https://doi.org/10.1002/jpln.200625192

[10] Farrell, M., Macdonald, L. M., Hill, P. W., Wanniarachchi, S. D., Farrar, J., Bardgett, R. D., & Jones, D. L. (2014). Amino acid dynamics across a grassland altitudinal gradient. Soil Biology and Biochemistry, 76, 179–182. https://doi.org/10.1016/j.soilbio.2014.05.015

[11] Gattinger, A., Muller, A., Haeni, M., Skinner, C., Fliessbach, A., Buchmann, N., Mäder, P., Stolze, M., Smith, P., Scialabba, N. E. H., & Niggli, U. (2012). Enhanced top soil carbon stocks under organic farming. Proceedings of the National Academy of Sciences of the United States of America, 109(44), 18,226–18,231. https://doi.org/10.1073/pnas.1209429109

[12] Hoyle, F. C., Baldock, J. A., & Murphy, D. V. (2011). Soil organic carbon—Role in rainfed farming systems. In P. Tow, et al. (Eds.), Rainfed farming systems (pp. 339–361). Netherlands: Springer. https://doi.org/10.1007/978-1-4020-9132-2_14

[13] Jiang, G., Shirato, Y., Xu, M., Yagasaki, Y., Huang, Q., Li, Z., Nie, J., & Shi, X. (2013). Testing the modified Rothamsted carbon model for paddy soils against the results from long-term experiments in southern China. Soil Science & Plant Nutrition, 59(1), 16–26. https://doi.org/10.1080/00380768.2012.733923

[14] Jiang, G., Xu, M., He, X., Zhang, W., Huang, S., Yang, X., Liu, H., Peng, C., Shirato, Y., Iizumi, T., Wang, J., & Murphy, D. V. (2014). Soil organic carbon sequestration in upland soils of northern China under variable fertilizer management and climate change scenarios. Global Biogeochemical Cycles, 28, 319–333. https://doi.org/10.1002/2013GB004746

[15] Ju, X., Zhang, F., Bao, X., Römheld, V., & Roelcke, M. (2005). Utilization and management of organic wastes in Chinese agriculture: Past, present and perspectives. Science in China Series C: Life Sciences, 48, 965–979

[16] Kirkby, C. A., Richardson, A. E., Wade, L. J., Batten, G. D., Blanchard, C., & Kirkegaard, J. A. (2013). Carbon-nutrient stoichiometry to increase soil carbon sequestration. Soil Biology and Biochemistry, 60, 77–86. https://doi.org/10.1016/j.soilbio.2013.01.011

[17] Kirkby, C. A., Richardson, A. E., Wade, L. J., Passioura, J. B., Batten, G. D., Blanchard, C., & Kirkegaard, J. A. (2014). Nutrient availability limits carbon sequestration in arable soils. Soil Biology and Biochemistry, 68, 402–409. https://doi.org/10.1016/j.soilbio.2013.09.032

[18] Li, Y., Huang, H., Ju, H., Lin, E., Xiong, W., Han, X., Wang, H., Peng, Z., Wang, Y., Xu, J., Cao, Y., & Hu, W. (2015). Assessing vulnerability and adaptive capacity to potential drought for winter-wheat under the RCP 8.5 scenario in the Huang-Huai-Hai Plain. Agriculture, Ecosystems and Environment, 209, 125–131. https://doi.org/10.1016/j.agee.2015.03.033

[19] Liang, B., Yang, X., He, X., Murphy, D. V., & Zhou, J. (2012). Long-term combined application of manure and NPK fertilizers influenced nitrogen retention and stabilization of organic C in Loess soil. Plant and Soil, 353(1-2), 249–260. https://doi.org/10.1007/s11104-011-1028-z

[20] Liang, Q., Chen, H., Gong, Y., Fan, M., Yang, H., Lal, R., & Kuzyakov, Y. (2012). Effects of 15 years of manure and inorganic fertilizers on soil organic carbon fractions in a wheat-maize system in the North China Plain. Nutrient Cycling in Agroecosystems, 92(1), 21–33. https://doi.org/10.1007/s10705-011-9469-6

[21] Liang, Q., Chen, H., Gong, Y., Yang, H., Fan, M., & Kuzyakov, Y. (2014). Effects of 15 years of manure and mineral fertilizers on enzyme activities in particle-size fractions in a North China Plain soil. European Journal of Soil Biology, 60, 112–119. https://doi.org/10.1016/j.ejsobi.2013.11.009

[22] Liu, J. G., & Diamond, J. (2005). China's environment in a globalizing world. Nature, 435(7046), 1179–1186. https://doi.org/10.1038/4351179a

[23] Lu, F., Wang, X., Han, B., Ouyang, Z., Duan, X., Zheng, H., & Miao, H. (2009). Soil carbon sequestrations by nitrogen fertilizer application, straw return and no-tillage in China's cropland. Global Change Biology, 15(2), 281–305. https://doi.org/10.1111/j.1365-2486.2008.01743.x

[24] Lu, R.K. (2000). Analytical methods of soil agricultural chemistry (in Chinese). China Agricultural Science and Technology Press, Beijing, China

[25] Luo, Z., Feng, W., Luo, Y., Baldock, J., & Wang, E. (2017). Soil organic carbon dynamics jointly controlled by climate, carbon inputs, soil properties and soil carbon fractions. Global Change Biology, 23(10), 4430–4439. https://doi.org/10.1111/gcb.13767

[26] Mader, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., & Niggli, U. (2002). Soil fertility and biodiversity in organic farming. Science, 296(5573), 1694–1697. https://doi.org/10.1126/science.1071148

[27] Maillard, E., & Angers, D. A. (2014). Animal manure application and soil organic carbon stocks: A meta-analysis. Global Change Biology, 20(2), 666–679. https://doi.org/10.1111/gcb.12438

[28] Mi, W. H., Sun, Y., Xia, S. Q., Zhao, H. T., Mi, W. T., Brookes, P. C., Liu, Y. L., & Wu, L. H. (2018). Effect of inorganic fertilizers with organic amendments on soil chemical properties and rice yield in a low-productivity paddy soil. Geoderma, 320, 23–29. https://doi.org/10.1016/j.geoderma.2018.01.016

[29] Ministry of Agriculture of the People's Republic of China (2015). The action plan for ineral fertilizer use zero-growth by 2020. Retrieved from http://www.moa.gov.cn/zwllm/tzgg/tz/201503/t20150318_4444765.htm

[30] Murphy, J., & Riley, J. P. (1962). A modified of single solution method for the determination of phosphate in nature water. Analytica Chimica Acta, 27, 31–36. https://doi.org/10.1016/S0003-2670(00)88444-5

[31] NBSC (National Bureau of Statistics of China) (2016). China statistical yearbook (in Chinese). Beijing, China: National Bureau of Statistics of China

[32] NCATS (National Center for Agricultural Technology Service) (1994). Chinese organic fertilizer handbook (in Chinese). Beijing, China: National Center for Agricultural Technology Service

[33] NCATS (National Center for Agricultural Technology Service) (2008). The dynamics of soil quality in arable land—The reorganizer of the data of national arable land observed station (in Chinese). Beijing, China: Agriculture and Technology Press in China

[34] Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate, (USDA Circ. 939). Washington, DC: U.S: Government Printing Office

[35] Pabst, H., Gerschlauer, F., Kiese, R., & Kuzyakov, Y. (2016). Land-use and precipitation affect organic and microbial carbon stocks and the metabolic quotient in soils of eleven ecosystems of Mt. Kilimanjaro, Tanzania. Land Degradation & Development, 27(3), 592–602. https://doi.org/10.1002/ldr.2406

[36] Pausch, J., & Kuzyakov, Y. (2018). Carbon input by roots into the soil: Quantification of rhizodeposition from root to ecosystem scales. Global Change Biology, 24(1), 1–12. https://doi.org/10.1111/gcb.13850

[37] Ponisio, L. C., M'Gonigle, L. K., Mace, K. C., Palomino, J., Valpine, P. D., & Kremen, C. (2014). Diversification practices reduce organic to conventional yield gap. Proceedings of the Biological Sciences, 282(1799), 20141396. https://doi.org/10.1098/rspb.2014.1396

[38] Qin, Z., Huang, Y., & Zhuang, Q. (2013). Soil organic carbon sequestration potential of cropland in China. Global Biogeochemical Cycles, 27, 711–722. https://doi.org/10.1002/gbc.20068

[39] Schmidt, M. W., Torn, M. S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I. A., Kleber, M., Kogel-Knabner, I., Lehmann, J., Manning, D. A., Nannipieri, P., Rasse, D. P., Weiner, S., & Trumbore, S. E. (2011). Persistence of soil organic matter as an ecosystem property. Nature, 478(7367), 49–56. https://doi.org/10.1038/nature10386

[40] Schrama, M., Haan, J. J. D., Kroonen, M., Verstegen, H., & Putten, W. H. V. D. (2018). Crop yield gap and stability in organic and conventional farming systems. Agriculture Ecosystems & Environment, 256, 123–130. https://doi.org/10.1016/j.agee.2017.12.023

[41] Schulze, E. D., & Freibauer, A. (2005). Carbon unlocked from soils. Nature, 437(7056), 205–206. https://doi.org/10.1038/437205a

[42] Seufert, V., Ramankutty, N., & Foley, J. A. (2012). Comparing the yields of organic and conventional agriculture. Nature, 485, 229. https://doi.org/10.1038/nature11069

[43] Shen, H. (1982). The method of soil nutrition map design (in Chinese). Soil and Fertilizers, 5, 21–22

[44] Shi, Y., Wang, L., Liu, S., & Nie, H. (2008). Development of chemical fertilizer industry and its effect on agriculture of China (in Chinese). Acta Pedologica Sinica, 45, 852–864. https://doi.org/10.3321/j.issn:0564-3929.2008.05.012

[45] Sun, W., Huang, Y., Zhang, W., & Yu, Y. (2010). Carbon sequestration and its potential in agricultural soils of China. Global Biogeochemical Cycles, 24, GB3001. https://doi.org/10.1029/2009GB003484

[46] Velthof, G. L., Oenema, O., Bannink, A., Van Der Meer, H. G., & Spoelstra, S. F. (2000). Relationships between animal nutrition and manure quality—A literature review on C, N, P and S compounds. Alterra, Green World Research, Wageningen, Alterra-rapport 063. Retrieved from http://edepot.wur.nl/28901 (accessed 26 December 2017)

[47] Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science, 37(1), 29–38. https://doi.org/10.1097/00010694-193401000-00003

[48] Wang, Y., Hu, N., Ge, T., Kuzyakov, Y., Wang, Z.-L., Li, Z., Tang, Z., Chen, Y., Wu, C., & Lou, Y. (2017). Soil aggregation regulates distributions of carbon, microbial community and enzyme activities after 23-year manure amendment. Applied Soil Ecology, 111, 65–72. https://doi.org/10.1016/j.apsoil.2016.11.015

[49] Wei, W., Yan, Y., Cao, J., Christie, P., Zhang, F., & Fan, M. (2016). Effects of combined application of organic amendments and fertilizers on crop yield and soil organic matter: An integrated analysis of long-term experiments. Agriculture, Ecosystems and Environment, 225, 86–92. https://doi.org/10.1016/j.agee.2016.04.004

[50] Wong, J. W. C., Ma, K. K., Fang, K. M., & Cheung, C. (1999). Utilization of a manure compost for organic farming in Hong Kong. Bioresource Technology, 67(1), 43–46. https://doi.org/10.1016/S0960-8524(99)00066-8

[51] Xu, M., Liang, G., & Zhang, F. (2006). Soil fertility evolution in China (in Chinese). Chinese Agricultural Science Technology, Beijing, China

[52] Yan, H., Cao, M., Liu, J., & Tao, B. (2007). Potential and sustainability for carbon sequestration with improved soil management in agricultural soils of China. Agriculture, Ecosystems and Environment, 121(4), 325–335. https://doi.org/10.1016/j.agee.2006.11.008

[53] Yan, X., Cai, Z., Wang, S., & Smith, P. (2011). Direct measurement of soil organic carbon content change in the croplands of China. Global Change Biology, 17(3), 1487–1496. https://doi.org/10.1111/j.1365-2486.2010.02286.x

[54] Yan, X., Yagi, K., Akiyama, H., & Akimoto, H. (2005). Statistical analysis of the major variables controlling methane emission from rice fields. Global Change Biology, 11(7), 1131–1141. https://doi.org/10.1111/j.1365-2486.2005.00976.x

[55] Yan, Y., Tian, J., Fan, M., Zhang, F., Li, X., Christie, P., Chen, H., Lee, J., Kuzyakov, Y., & Six, J. (2012). Soil organic carbon and total nitrogen in intensively managed arable soils. Agriculture, Ecosystems and Environment, 159, 102–110. https://doi.org/10.1016/j.agee.2012.01.024

[56] Yang, F., Li, R., Cun, Y., & Duan, Y. (2010). Utilization and develop strategy of organic fertilizer resources in China. Soil and Fertilizer Sciences in China, 4, 77–82

[57] Yu, Y., Guo, Z., Wu, H., Kahmann, J. A., & Oldfield, F. (2009). Spatial changes in soil organic carbon density and storage of cultivated soils in China from 1980 to 2000. Global Biogeochemical Cycles, 23, GB2021. https://doi.org/10.1029/2008GB003428

[58] Zhang, W., Liu, K., Wang, J., Shao, X., Xu, M., Li, J., Wang, X., & Murphy, D. V. (2015). Relative contribution of maize and external manure amendment to soil carbon sequestration in a long-term intensive maize cropping system. Scientific Reports, 5(1), 10791. https://doi.org/10.1038/srep10791

[59] Zhang, W., Wang, X., Xu, M., Huang, S., Liu, H., & Peng, C. (2010). Soil organic carbon dynamics under long-term fertilizations in arable land of northern China. Biogeosciences, 7(2), 409–425. https://doi.org/10.5194/bg-7-409-2010

[60] Zhang, W., Xu, M., Wang, X., Huang, Q., Nie, J., Li, Z., Li, S., Hwang, S. W., & Lee, K. B. (2012). Effects of organic amendments on soil carbon sequestration in paddy fields of subtropical China. Journal of Soils and Sediments, 12(4), 457–470. https://doi.org/10.1007/s11368-011-0467-8

[61] Zhao, M., Zhou, J., & Kalbitz, K. (2008). Carbon mineralization and properties of water-extractable organic carbon in soils of the south Loess Plateau in China. European Journal of Soil Biology, 44(2), 158–165. https://doi.org/10.1016/j.ejsobi.2007.09.007